THE RELATIVE REACTIVITY OF FORMIC ESTERS WITH AROMATIC AMINES.

A THESIS SUBMITTED TO THE FACULTY OF
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THE DEGREE OF BACHELOR OF SCIENCE
IN CHEMICAL ENGINEERING

BY
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PREFACE.

The purpose of this thesis was to determine the relative reactivity between aromatic amines and the esters of formic acid.It was proposed to first determine the reactivity of five representative formic esters with several of the amines,then to use one or two esters and determine the relative reactivity of a number of amines.

The general reaction is represented by the following equation-

$RC_6H_4NH_2$ plus HCOOR'gives $RC_6H_4NH(CHO)$ plusR'OH

in which R is any radicle particular to the amine and R" the alcohol radicle of the formic ester.However in the case of phenyl hydrazine the reaction is slightly different,it is as follows-

$C_6H_5NHNH_2$ plusHCOOR'gives $C_6H_5NHNH(CHO)$ plus R'OH.

As above indicated the reaction gives a formamide and an alcohol.The first step is to determine the conditions under which this reaction would take place.The next step is to devise methods for quantitatively separating the formamide and then identifying it.

The only published information on this reaction is that in the work of two Russian chemists,L.Bordakowsky and S.Reformatsky[1] who found that if phenyl hydrazine

1.L.Bordakowsky and S.Reformatsky,1903,J.R.P.C.G.

was heated for three hours at sixty degrees with a formic ester an eighty percent yield of formyl phenyl hydrazid was secured; and in the work of Broll who in 1875 at Hamburg secured ortho-formo-phenetidid from ethyl formate and ortho-phenetidin.[1]

Much credit must be given Dr.Ray Q.Brewster,the director of this work, for his help and directions for carrying out this work, and to Dr.Frank B.Dains for his kind assistance in many ways.

1.Broll,Journal fur Practische Chemie,1875,vol. 12,page 208.

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PREPARATION AND PURIFICATION OF REAGENTS.

Methyl formate was made in the usual manner for preparing an ester by the interaction of methyl alcohol and formic acid using concentrated sulphuric acid as the dehydrating agent. 400c.c.of methyl alcohol and 300 grams of 90 percent formic acid were mixed together in a two liter round bottom flask,then 250 grams of sulphuric acid,specific gravity 1.84,were added very slowly with shaking,care being taken to avoid heating above 30° to avoid loss by volatilization of the methyl formate.No formation of carbon monoxide by the interaction of the formic and sulphuric acids was noticed.The flask was then fitted with two vertical water jacketed condensors in series,and then gently refluxed for two hours.At the end of the two hours the condensors were removed and a fractionating column substituted for them.The methyl formate was then fractionally distilled over.After several fractionations a constant boiling fraction of 35° was obtained. The recorded boiling point is 33°.[1] The yield calculated on the weight of the formic acid used was 41 percent. This low figure was accounted for by the unavoidable losses of methyl formate by volatilization.

1.Handbook of Chemistry and Physics,page 209.

Chemically pure ethyl formate(Eastman) was available and was used with out any further purification.

Normal propyl formate made in a similar method to that used in preparing the methyl ester. However the elaborate precautions necessary to prevent the volatilization of the ester in the preparation of the methyl formate were unnecessary in this case. 250 c.c.of normal propyl alcohol and175 grams of 90 percent formic acid were mixed in a one liter round bottom flask,then 125 grams of concentrated sulphuric acid were added. The mixture was then refluxed for two hours,then the normal propyl formate was fractionated off. A constant boiling fraction at 81° was obtained. The recorded boiling point is 81°.[1] A yield of 97 percent was obtained.

Normal butyl formate(Eastman,chemically pure) was in stock and was used with out any further purification. Hereafter whenever propyl or butyl formate is referred it will be understood to mean the normal ester.

The preparation of secondary octyl formate was attempted by the foregoing method but the only products obtained were sulphur dioxide and a hard coke like mass. The concentrated sulphuric acid evidently acted as an oxidizing agent with the secondary octyl alcohol.

1.Handbook of Chemistry and Physics,page230.

Another method must therefor be used,so 43.4 grams of the secondary octyl alcohol and 20.0 grams of 90 percent formic acid were mixed in a 500 c.c.round bottom flask and an air reflux condensor attached. Hydrogen chloride gas was passed in in a steady stream while the contents of the flask were being refluxed for two hours. The hydrogen chloride gas was prepared by treating salt with sulphuric acid in the cold. The secondary octyl formate was separated by fractional distillation. A constant boiling fraction at 198° was obtained. No recorded constants on secondary octyl formate could be found. The yield was 57 percent calculated on the weight of alcohol used.

Phenyl hydrazine was obtained as the dark colored commercial product. This was redistilled. A constant boiling fraction at 238° was obtained. The recorded boiling point is 243.5°.[1]

Aniline was obtained as the dark impure commercial product. This was twice redistilled over metallic zinc (to reduce any nitrobenzene that might be present). The resulting product being of a light straw color with a boiling point of 182°. The recordedboiling point is 184.4°.[2]

1.Handbook of Chemistry and Physics,page 227.

2. " " " " " " 150.

Commercial para-toluidine of sufficient purity for this work was obtainable, and was used without any further purification.

Student preparation para-chlor-aniline was further purified by redistillation with steam. It was then filtered from free water and dried on a porous plate. The purified product melted at 73°, the recorded melting point being 70°.[1]

Para-brom-aniline of similar origin was purified in the same manner as the para-chlor-aniline. The purified product melted at 57°, the recorded melting point being 63°.[2]

Para- and meta-nitraniline were obtainable in sufficient purity for this work and were not further purified.

Alpha-naphthyl amine was on hand in sufficient purity. The product melted at 50° which is the recorded melting point.[3]

Para-phenetidin (commercial) was used with out purification.

1. Richter vol. I, page 412.

2. " " " " "

3. Van Nostrand, Chemical Annual, page .

FORMIC ESTERS WITH PHENYL HYDRAZINE.

This reaction was investigated to a slight extent by two Russian chemists who reported forming formyl phenyl hydrazide by heating together phenyl hydrazine and a formic ester at about 60° for three hours.[1]

A trial run was made with methyl and propyl formates. Tenth molar quantities of both the esters and the phenyl hydrazine were weighed into pressure flasks and heated at 60° for 30 minutes. The formyl phenyl hydrazide separated out as a slightly reddish crystalline solid. The contents of the flasks were removed to filters and washed with a mixture of equal parts of gasoline and benzene. The formyl phenyl hydrazine is insoluble in this solvent while the esters, phenyl hydrazine, and alcohols are soluble in it. The washed formyl phenyl hydrazine was dried first on a porous plate then in an oven at 100°. The purified formyl phenyl hydrazide was a white crystalline solid. That made from methyl formate had a melting point of 141° while that from propyl formate melted at 139.5°. The recorded melting point is 140-145°.[2] The methyl formate gave a 27 percent yield and the propyl formate a 55 percent yield. It was noticed that the formyl

1. L.Bordakowsky & S.Reformatsky, J.Russ.Phys.Chem. Ges., vol.35, page61

2. Richter, vol.I, page 651.

phenyl hydrazide began to separate out immediately upon mixing the propyl formate and the phenyl hydrazine.

It was then decided to make a rum at room temperatures. Tenth molar quantities of the methyl,ethyl, propyl,and butyl esters were weighed into 200 c.c. bottles with tenth molar quantities of phenyl hydrazine. The bottles were allowed to stand for 48 hours at room temperatures (20-25°). At the end of this time the contents of the bottles were found to be all solidified. The formyl phenyl hydrazide was recovered in the same manner as above except that the benzene had to be ommitted from the wash owing to its being unobtainable at that time. The resulting product had a reddish color that the gasoline could not completely wash out. The yields and melting points were as follows-

Ester used	Percent yield	Melting point
Methyl formate	80%	142%
Ethyl "	94	141
Propyl "	100	140
Butyl "	96	141

A one hour run was made with the four esters used in the preceding run with secondary octyl formate additional. The same quantities and bottles were used as above with the exception of secondary octyl formate

in which owing to its high cost twentieth molar quantities were used. The recovery was the same as for the 48 hour run.The yields were as follows-

Ester used	Percent yield
Methyl formate	15%
Ethyl "	39
Propyl "	44
Butyl "	15
Sec.octyl "	12

A five hour run under the same conditions was made with the methyl,ethyl,propyl,and butyl formates. This run checked the reactivity ratio established by the preceding runs. The yields were as follows-

Ester used	Percent yield
Methyl formate	40%
Ethyl "	42
Propyl "	45
Butyl "	41

All percentage yields are calculated on the weight of amine used.

FORMIC ESTERS WITH ANILINE.

The first problem in this reaction was the separation of the formanilid from the alcohol formed with it and any remaining ester and aniline. With the exception of the secondary octyl formate and alcohol all the esters and alcohols can be removed by evaporating to constant weight in a 100° oven. The anilin is soluble in a saturated acidified salt solution while the formanilid is not. Two grams of formanilid were mixed in with five grams of anilime, the acidified salt solution was then added, and the insoluble oil extracted with ether. The ether was evaporated off and the remaining oil weighed, the recovery was practically 100 percent. In the case of the secondary octyl formate it would not be practical to evaporate off the ester and alcohol so the remaining anilime is removed by the acidified salt solution, and the formanilid allowed to crystallize out. After which it is filtered off and dried on a porous plate.

Tenth molar quantities of the methyl, ethyl, propyl, and butyl formates were weighed into pressure flasks with tenth molar quantities of aniline. The flasks are then suspended in a 100° (boiling water) bath for two

hours. AT the end of the two hours the withdrawn, opened,and acidified salt solution added. The oil was then extracted with ether and evaporated at 100° to constant weight. The resulting formanilid was a thick brown oil which becomes crystalline after standing some days. It was impractical to get a melting point determination on this sort of a product. The yields Were as follows-

Ester used	Percent yield
Methyl formate	58%
Ethyl "	68
Propyl "	83
Butyl "	66

The high yields obtained in the preceding run lead to the decision to make a one hour run under the same conditions. In addition twentieth molar quantities with secondary octyl formate were used.The results were as follows-

Ester used	Percent yield
Methyl formate	42%
Ethyl formate	66
Propyl formate	73
Butyl formate	57
Sec.octyl formate	9

FORMIC ESTERS WITH PARA-TOLUIDINE.

The next amine chosen was para-toluidine, it was then decided to run it in the same manner as aniline using the pressure flasks and heating at 100°. Tenth molar quantities of the methyl, ethyl, propyl, and butyl formates, and twentieth molar quantities of the secondary octyl formate were weighed into pressure flasks with respective molar quantities of the para-toluidine and heated for one hour in a boiling water bath at 100°. The contents of the flasks began to darken almost at o once on heating, and by the end of the hour were quite dark. At the end of the hour the flasks were removed from the bath, cooled, and acidified salt solution added. The oily layer extracted with ether, except that in the case of the secondary octyl ester when the formotoluid was allowed to crystallize out. The ether extracts wre reduced to constant weight at 100°. The resulting para-formotoluid was a thick dark oil which solidified after standing some days. No attempt was made to get a melting point on this crude product.

Five hour runs were made with ethyl and propyl formates at room temperatures. Data on these runs will be given in a later portion of this paper.

The results on the one hour heat at 100° are as follows-

Ester used	Percent yield
Methyl formate	8%
Ethyl "	81
Propyl "	92
Butyl "	80
Sec.octyl "	10

PROPYL FORMATE WITH SEVERAL AMINES

The next move was to secure data on the relative reactivity of the amines. Seven different amines were chosen for this series of runs. They were phenyl hydrazine, aniline, para-toluidine, para-chloraniline, para-bromaniline, para-nitraniline, and meta-nitraniline. One ester was run under the same conditions with each of the amines. Propyl formate was chosen as the ester because of its high degree of reactivity and the ease of its manufacture.

The five hour run of propyl formate and phenyl hydrazine described on page eleven of this paper was taken as the basis for securing this data and similar runs were made with each of the other amines.

Tenth molar quantities of aniline and propyl formate were weighed into a 200 c.c. bottle and let stand at room temperatures for five hours. At the end of the five hours acidified saturated salt solution was added and the oil insoluble in the solution separated off. Ether was added to the oil, this threw down the formanilid as a light colored precipitate. This was filtered off, dried on a porous plate and weighed. The yield was 9.9 percent. The melting point was 45°. The

recorded melting point is 46°.[1]

Fourtieth molar quantities of para toluidine and propyl formate were weighed into a 200 c.c.bottle and let stand at room temperatures for five hours. At the end of the five hours acidified saturated salt solution was added. The p-formotoluid separated out as a pale yellow crystalline solid which was filtered off,dried on a porous plate,and weighed.It melted at 55°,the recorded melting point being 52-3°.[2] The percentage yield was 17.9 percent.

Tenth molar quantities of para chloraniline and propyl formate were mixed in a 200 c.c.bottle and let stand for five hours at room temperatures. The paformo-chloranilid was separated in the same manner as the p-formotoluid.The yield was 27.6 percent. The para-formo-chloranilid melted at 103° whereas the recorded melting point is 102°.[3]

Twentieth molar quantities of para-bromaniline and propyl formate were weighed into a 200c.c.bottle and let stand at room temperatures for five hours. The para-bromO-formanilid was separated in the same manner as

1.Beilstein,Auf.,vol.II,page 358.

2. " " " " "490.

3. " Erg.(" " " 167.

the para chlor. The melting point was 117.3° whereas the recorded melting point is 119°[1]. The yield was 78.0 percent.

Twentieth molar quantities para nitraniline and propyl formate were weighed into a 200 c.c. bottle and let stand for five hours at room temperatures. The para formonitranilid was separated in the same manner as the para formotoluid. The yield was 90.3 percent. The melting point was 175° after recrystallization from boiling water. The recorded melting point is 187-194°[2].

Tenth molar quantities of meta-nitraniline and propyl formate were weighed into a 200 c.c.bottle and let stand at room temperatures for five hours. The separation of the meta-formonitranilid is the same as for the para-formotoluid. The yield was 86.8 percent. The melting point was 137°. The recorded melting point is 134°[3].

The yields with propyl formate are as follows-

1.Beilstein,Auf.,vol.II,page 358.

2. " " " " " 359.

3. " " " " " ".

Propyl formate five hours at room temperatures.

Phenyl hydrazine	45.0%
Aniline	9.9
Para-toluidine	17.9
Para-chloraniline	27.6
Para-bromaniline	78.0
Para-nitraniline	90.3
Meta-nitraniline	86.8

ETHYL FORMATE WITH SEVERAL AMINES.

In order to check the results obtained with the propyl formate it was next decided to run a series of amines with ethyl formate, it being nearly as reactive as the propyl ester. The amines used were para-toluidine para-nitraniline, alpha naphthyl amine, and para-phenetidin (para-amino-phenyl-ethyl ether). The conditions were the same as in the runs with propyl formate, five hour runs at room temperatures.

The five hour run of ethyl formate with phenyl hydrazine described on page eleven of this paper also fits in with this series of runs and is included in the results of this series.

Twentieth molar quantities of para-toluidine and ethyl formate were weighed into a 200 c.c. bottle and let stand for five hours at room temperatures. At the end of this time acidified saturated salt solution was added. The para-formotoluid separated out as a white crystalline solid and was filtered off, dried on a porous plate and weighed. The yield was 45.6 percent.

Twentieth molar quantities of para-nitraniline and ethyl formate were weighed into a 200 c.c. bottle and let stand for five hours at room temperatures. At the end of this time acidified saturated salt solution was added. The para-formonitranilid separated out as a

white crystalline substance which was separated by filtration, then dried on a porous plate and weighed. The yield was 61.9 percent.

Twentieth molar quantities of alpha naphthyl amine and ethyl formate were weighed into a 200 c.c. bottle and let stand for five hours at room temperatures. At the end of this time acidified saturated salt solution was added. A white solid separated out. It was weighed after drying on a porous plate and a melting point determination run on it. It was unchanged in state on heating to 200° whereas alpha formonaphthalide has a melting point of 138.5°.[1] It was then recrystallized from boiling water, dried and weighed. The recrystallized product melted at 140° thus showing it to be alpha formonaphthalid the desired product. The rest of the original substance was naphthyl amine hydrochloride. The yield was 45.5 percent.

Twentieth molar quantities of para phenetidin and ethyl formate were weighed into a 200 c.c. bottle and let stand for five hours at room temperatures. At the end of the five hours acidified saturated salt solution was added. Para phenetidin hydrochloride separated out as a solid and was filtered off immediately. The filtrate

1. Beilstein, Auf., vol. II, page 605.

was allowed to stand until the para formylphenetidid crystallized out. It was then filtered off,dried on a porous plate,and weighed. It had a melting point of 70°,the recorded melting point being 67°.

The results of this series of runs are as follows-

Amine used	Percent reacted.
p-nitraniline	61.9%
p-toluidine	45.6
a-naphthyl amine	45.5
Phenyl hydrazine	42.0
p-phenetidin	16.5

FORMIC ESTERS WITH PHENYL HYDRAZINE IN BENZENE-GASOLINE SOLUTION.

It was then decided to see what effect having the ester and amine in solution in some suitable solvent in which the resulting formamide would be extremely insoluble. Such requirements were met by the benzene gasoline solution used in the runs with phenyl hydrazine So twentieth molar quantities of ethyl and butyl formates were weighed into 200 c.c.bottles with a similar quantity of phenyl hydrazine. The bottles each contained 100 c.c.of a mixture of equal parts of benzene and gasoline. At intervals the formyl phenyl hydrazine was filtered off,dried in the 100° oven,and weighed. The yields at different times were as follows-

Time run	Yield ethyl formate	Yield propyl formate
10 min.	5.9%	3.0%
40 "	7.4	3.7
80 "	8.8	4.4
145 "	10.3	5.4

CONCLUSION.

The main object of this research was to ascertain the relative reactivity of the formic esters with aromatic amines. A secondary object was to find the relative reactivity of the amines with the esters.

In every case the normal propyl formate was the most reactive of the esters. Ethyl formate very closely approaches it in reactivity. Next in order is the butyl ester with methyl fourth and the secondary octyl formate last. It was expected that the methyl formate would be the most reactive and that the reactivity would decrease with increase in the molar weight of the ester. This order is followed by the propyl, butyl, and secondary octyl formates, but the methyl and ethyl esters are extremely out of place in such a series. It may be noted however that the methyl and ethyl formates and the corresponding methyl and ethyl alcohols are very high in solvent power while the other esters used and their corresponding alcohols are rather poor solvents. This solvent action may have a retarding effect on the production of the formamides from the methyl and ethyl esters. This view is strengthened by the behavior of the different amines.

It was expected that the amines would react in the order of their bascity,the more highly basic being the most reactive but the results indicate a general trend to the reverse although not in all cases. The most reactive is para nitraniline. There are two suggestions offered for this phenomenum,the first being the high degree of insolubility of the para formonitranilid causing the speeding up of the reaction owing to there being practically no state of equilibrium between the final product and the ester and amine as might be the case with a more soluble product. The second suggestion was that the presence of the nitro group might make one of the amino hydrogens much more easy tO displace as is the case with nitrophenol in which the hydrogen of the hydroxyl group is far more reactive than the similar hydrogen in unsubstituted phenol.

The order of reactivity of the amines beginning with the most reactive is as follows- para nitraniline, meta nitraniline,para bromaniline,alpha naphthyl amine, phenyl hydrazine,para chloraniline,para toluidine,para phenetidin,and aniline.

The reactivity is apparently in inverse ratio to

the solubility of the formamide but as there is but little quantitative data available on the solubilities of this class of substances and time did not permit the securing of it in this work the above statement cannot be taken as the final rule for the reactivity of amines with formic esters.

It was noticed that the rate of reaction of phenyl hydrazine changed and became much slower when the formyl phenyl hydrazine began to be precipitated from the solution. When only the ester and the amine were originally present this condition was reached when about 40 percent had reacted. A run was then made in which the ester and the phenyl hydrazine were dissolved in a mixture of benzene and gasoline in which the formyl phenyl hydrazine is extremely insoluble. This time the break in the curve occured at about five percent reacted the slope of the succeding portion of the curve having approximately the same slope as the latter portion of the first curves. This shows that solubility plays a considerable part in determining the rate of this reaction between esters and amines.

TABULATED RESULTS.

Amine	Time	Temp.	Ester				
			Methyl	Ethyl	Propyl	Butyl	Sec. Octyl
Phenyl hydrazine	½hr.	60°	27%		55%		
	1 "	room	15	39%	44	15 %	12%
	5 "	"	40	42	45	41	
	48 "	"	80	94	100	96	
Aniline	1 "	100°	42	66	73	57	9
	2 "	"	58	68	83	66	
	5 "	room			9.9		
P-toluid.	1 "	100°	8	81	92	80	10
	5 "	room		46	18		
p-chlorananiline	5 "	"			27.6		
p-bromaniline	5 "	"			78.0		
p-nitraniline	5 "	"		61.9	90.3		
m-nitraniline	5 "	"			86.8		
a-naphthyl amine	5 "	"		45.5			
p-phenetidin	5 "	"		16.5			

PLATE NUMBER ONE.

RELATIVE REACTIVITY OF FORMIC ESTERS WITH AMINES.

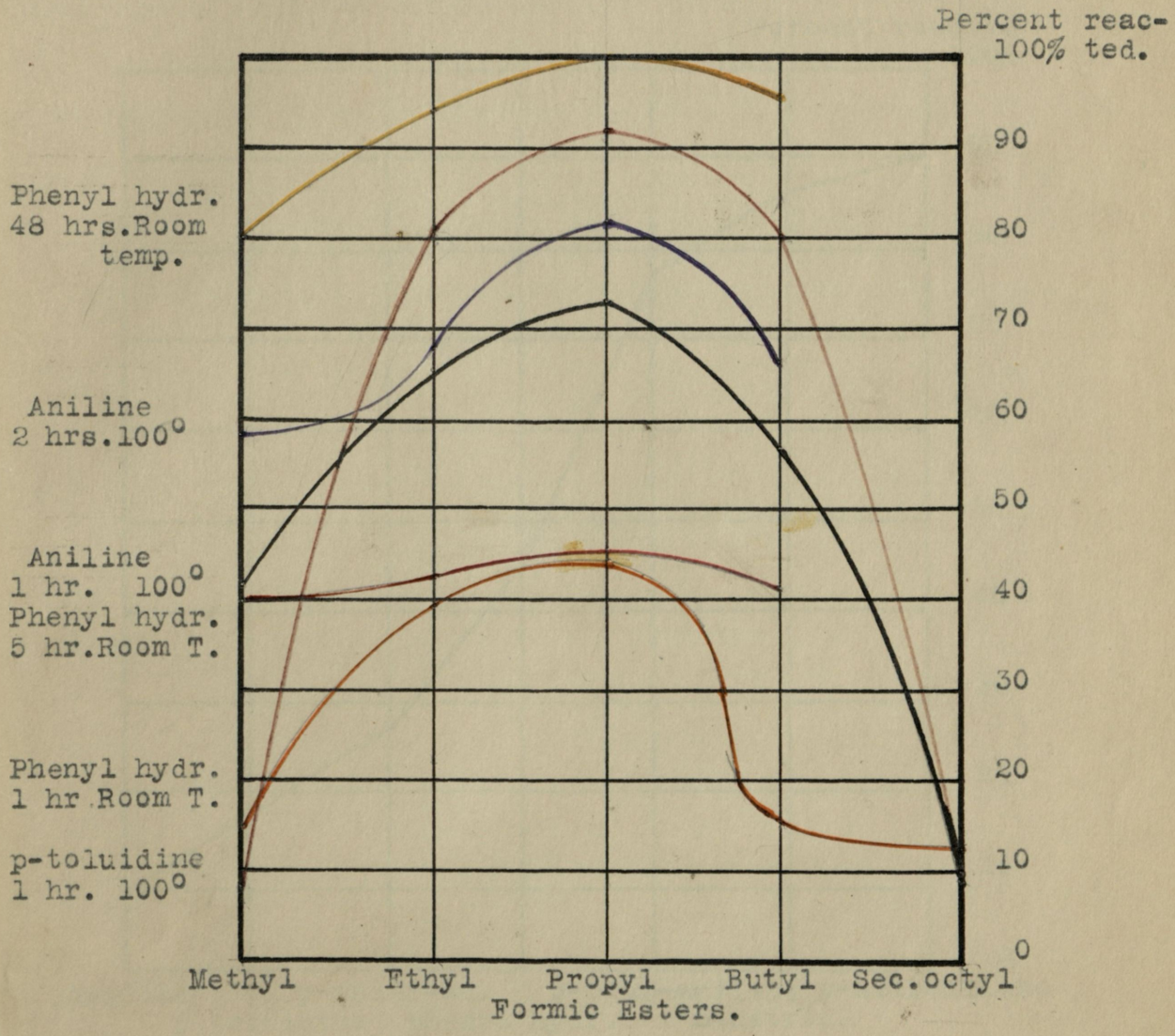


PLATE NUMBER TWO

RELATIVE REACTIVITY OF PROPYL FORMATE WITH AMINES.

Five hour runs at room temperatures.

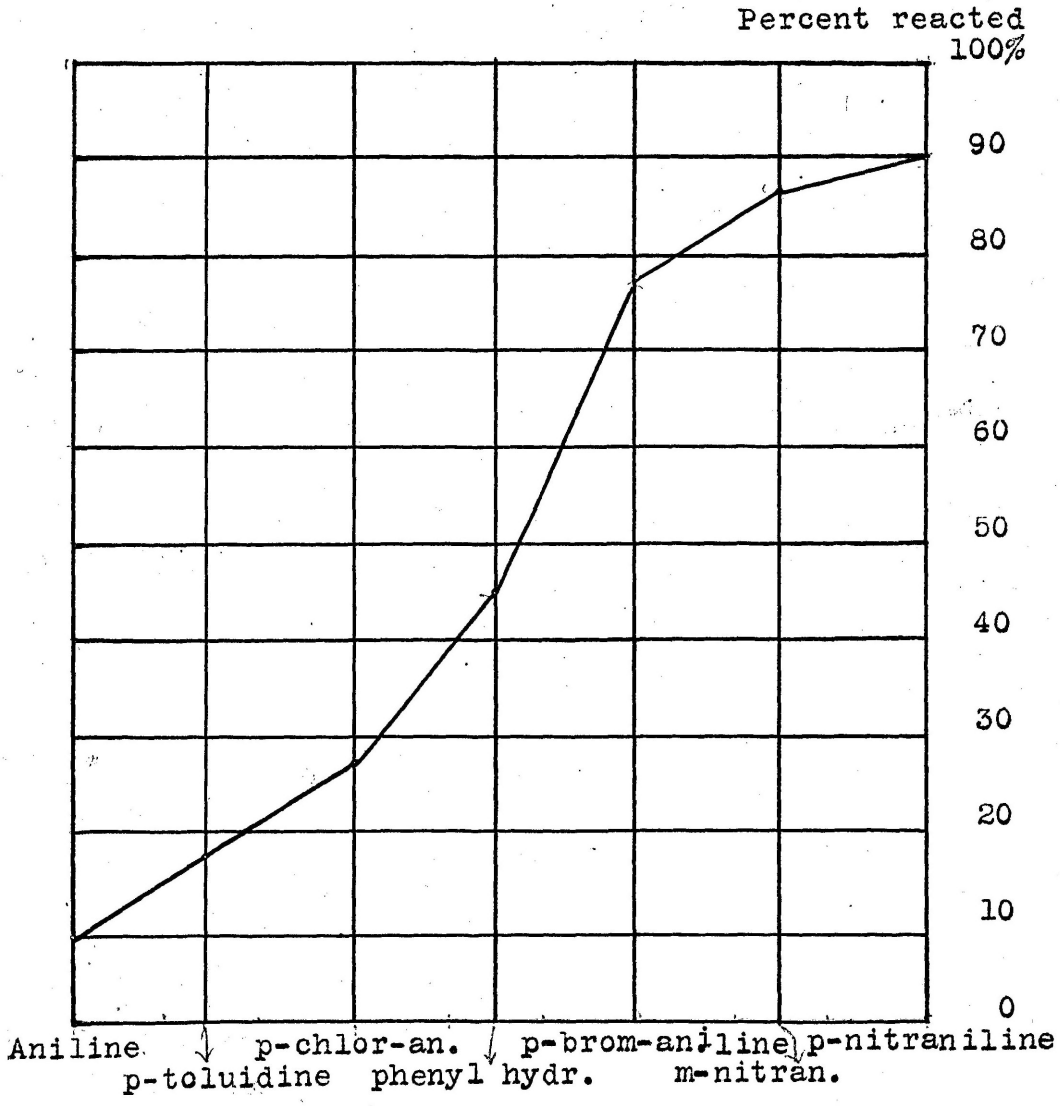


PLATE NUMBER RHREE.

RELATIVE REACTIVITY OF ETHYL FORMATE WITH AMINES.

Five hour runs at room temperatures.

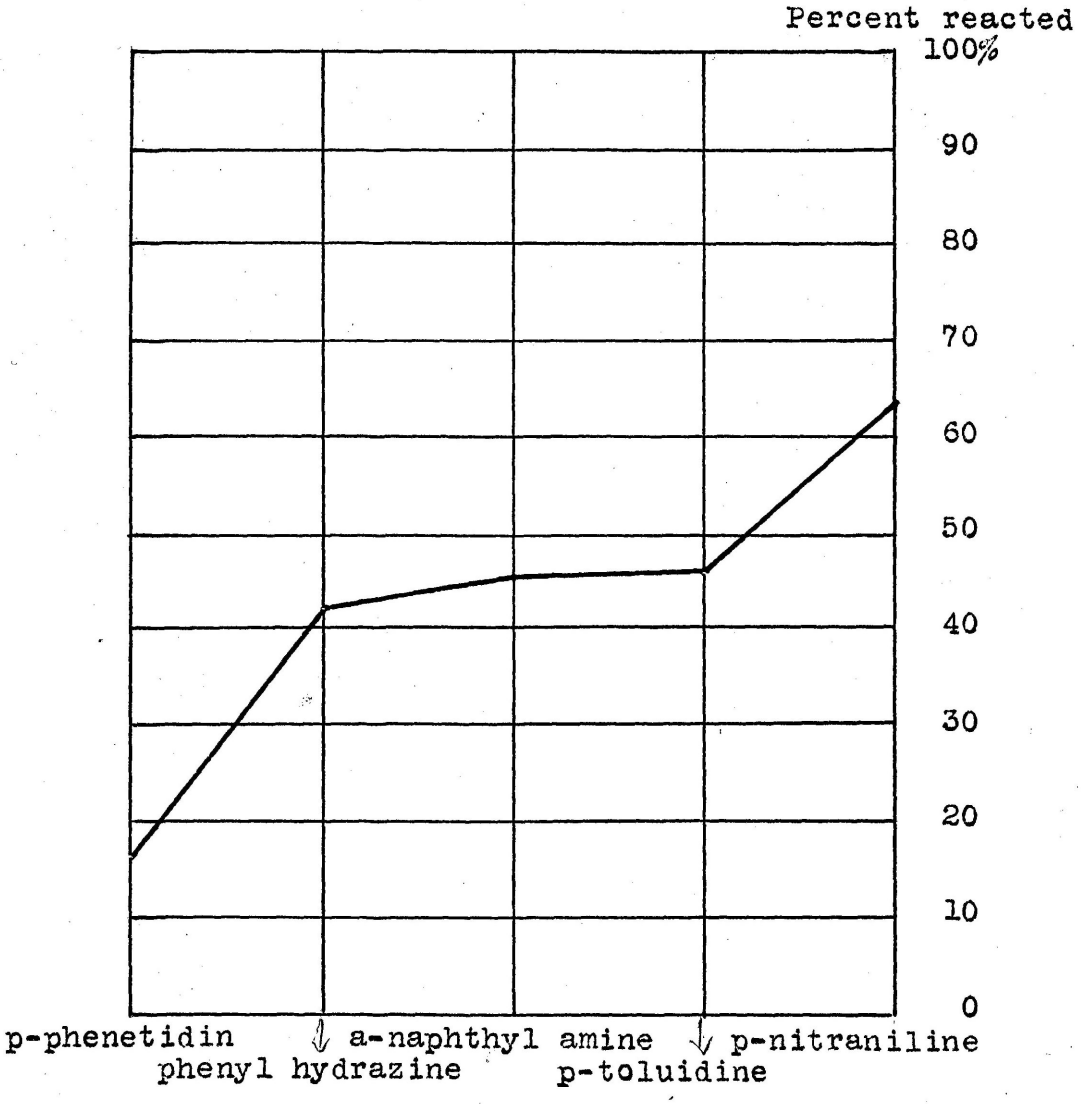


PLATE NUMBER FOUR.

FORMIC ESTERS WITH PHENYL HYDRAZINE AT ROOM TEMPERATURES

Time is not plotted to a uniform scale.

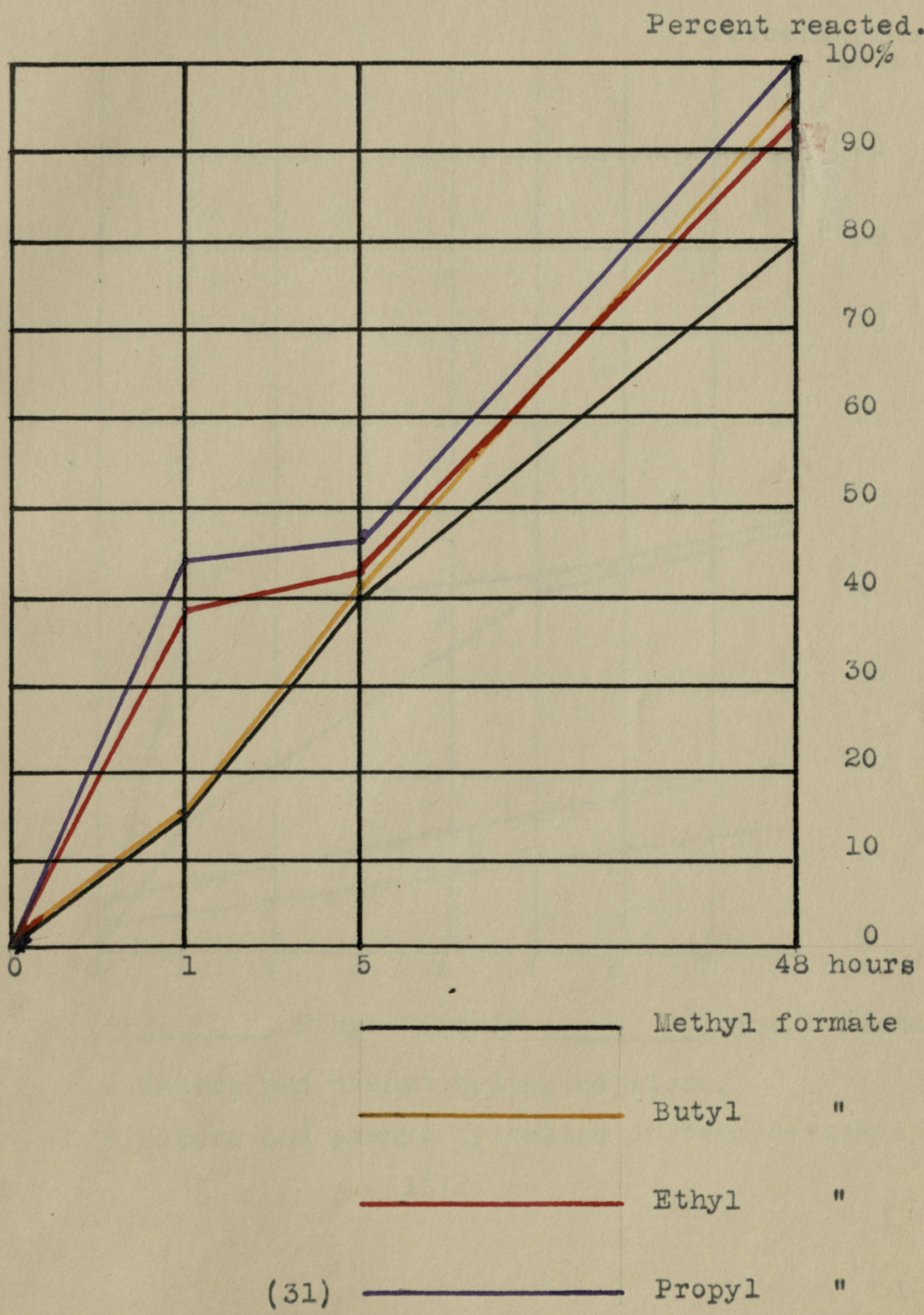
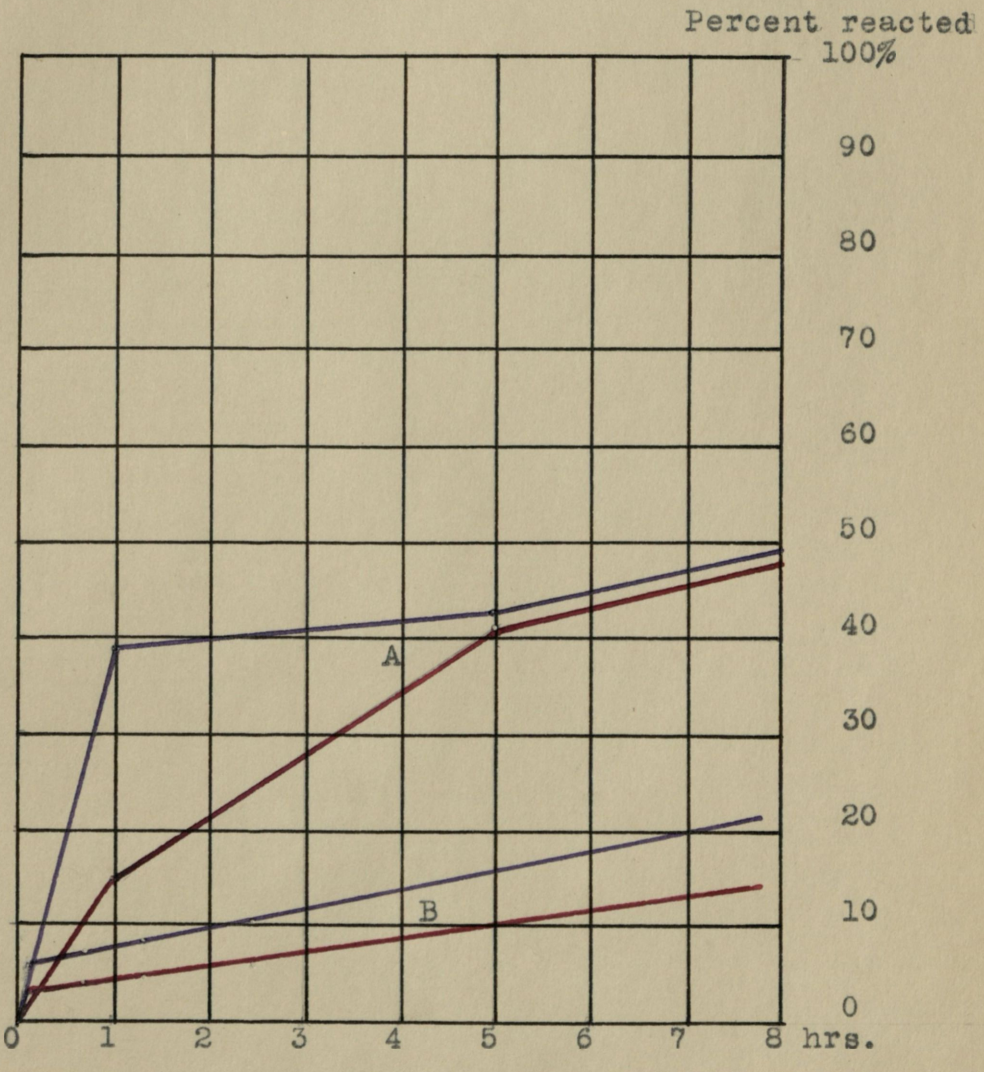


PLATE NUMBER FIVE.

PHENYL HYDRAZINE AND ETHYL AND BUTYL FORMATES.

Runs at room temperatures.



Ethyl formate Butyl formate

A.Esters and phenyl hydrazine alone.

B.Esters and phenyl hydrazine in benzene-gasoline.